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Enamel gloss changes induced by orthodontic bonding

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Abstract: OBJECTIVE: The purpose of this study was to assess enamel gloss changes induced by orthodontic bracket bonding with a light-cured composite or a light-cured resin-reinforced glass ionomer cement. SETTING: The Department of Biomaterials, School of Dentistry, National and Kapodistrian University of Athens, Greece. DESIGN: Laboratory study. METHODS: A total of twenty extracted upper human first premolars were included in this study and each tooth served as a control for itself. Their buccal surfaces were subjected to 60o-angle gloss measurement (G%60) with a standardized and secure repeated analysis of the same site. After baseline evaluation, a bracket was bonded on the buccal surface of each tooth. Half of the specimens were bonded with acid-etching and a light-cured composite whereas the other half with a light-cured resin-reinforced glass ionomer cement without prior enamel conditioning. Gloss measurements were repeated after bracket debonding and removal of the composite/glass ionomer cement with an 18-fluted carbide bur. Gloss differences between the two measurement conditions (baseline and post-debonding) were analyzed through linear regression with standard errors derived using the bootstrap method. Level of significance was set at a < 0.05. RESULTS: A statistically significant difference was detected between the tested groups for the outcome of interest. Teeth bonded with light-cured composite exhibited larger enamel gloss changes as compared to resin-reinforced glass ionomer cement (= 0.74; 95% CIs: 0.10, 1.38; p = 0.02). CONCLUSIONS: Bracket bonding with two common bonding protocols (acid-etching with a light-cured composite vs. no etching with resin reinforced glass-ionomer cement) and subsequently debonding and adhesive removal with an 18-fluted carbide bur induced enamel gloss changes.

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Results: A statistically significant difference was detected between the tested groups for the outcome of interest. Teeth bonded with light-cured composite exhibited larger enamel gloss changes as compared to resin-reinforced glass ionomer cement (β= 0.74; 95% CIs: 0.10, 1.38; p= 0.02).

Conclusions: Bracket bonding with two common bonding protocols (acid-etching with a light-cured composite vs. no etching with resin reinforced glass-ionomer cement) and subsequently debonding and adhesive removal with an 18-fluted carbide bur induced enamel gloss changes.

Key words: gloss, debonding, light-cured composite, glass-ionomer cement, carbide bur

The authors declare no conflict of interest, in accordance with Taylor & Francis policy and the ethical obligation as researchers.

Introduction

Orthodontic debonding involves the use of rotary instruments for the elimination of the remaining adhesive, however, there is a notable lack of a universally approved protocol for this potentially litigious treatment procedure (van Waes et al. 1997; Osorio et al. 1998; Janiszewska-Olszowska et al. 2016; Mohebi et al. 2017). The alterations of the enamel surface induced by rotary instruments may be irreversible and occasionally, composite resin residues may be found even after 30 sec of polishing the debonded surface (Vieira et al. 1993), whilst the amount of residual resin may be product-dependent (Irinoda et al. 2000). Recent research did not find any significant differences in the mechanical properties (Martens hardness, elastic modulus, and elastic index) and elemental composition of intact and etched/bonded with composite resin/debonded enamel, with the possible exception of silicon traces, which were found only in the latter (Ioannidis et al. 2018).

Optical stability of the enamel, regarding its colour, translucency and gloss is crucial after orthodontic treatment. In general, the adverse effects on enamel induced by orthodontic bracket bonding and debonding entail a wide array of processes taking place during acid-etching, fixed orthodontic treatment, and debonding (Sandison 1981). The corresponding alterations include enamel loss induced by enamel etching, inhibition of remineralization by saliva for the area bonded during treatment as well as scratches, and fractures induced on the surface during resin cleaning (Eliades et al. 2004). These parameters may affect the enamel colour to a varying extent as suggested by the fact that acid etching and debonding-cleaning procedures have been shown to lead to alteration of the uppermost enamel layer in the order of 10 μm for acid-etching–mediated bonding (Boncuk et al. 2014; Zhu et al. 2014). The literature indicates that colour and roughness changes after debonding correspond to irreversible structural and colourimetric alterations induced by orthodontic bonding and debonding. In these studies, the use of glass-ionomer was not capable of diminishing the potency of effects observed on enamel surface relative to composite resin bonding, implying that the procedure of resin grinding was more invasive than the preparation of enamel with acid etching (Eliades et al. 2001). However, these colour changes may not be clinically visible by the human eye (Trakyali et al. 2009). In contrast to composite resins, bracket bonding with a resin-modified glass ionomer cement requires no prior etching and may result in lower adhesion strength but significantly reduced enamel demineralization. Differences in enamel surface properties are expected between the two techniques too (Ferreira et al. 2014).

Apart from the colour and roughness variables, the perception of the texture and colour of a surface is influenced by its gloss variance. Enamel gloss is an optical property which indicates how well the enamel reflects light in a specular (mirror-like) direction. Gloss is represented by the degree of shine of a surface and is basically a measure of the difference of the angles formed between the incident and reflected light. The ratio of the angle of specular reflection over that of incidence, which is defined as reflectance, has been shown to be roughness-dependent. Increased roughness results in the formation of multiple reflecting sites within the same location, with different direction of prism orientation, leading to random or diffuse reflections. Polishing may eliminate enamel surface roughness, which may improve reflection of light (Trakyali et al. 2009).

The hypothesis tested in this paper was that orthodontic bonding and debonding results in the significant surface alteration of the enamel with measurable effects on gloss. Thus, the purpose of this study was to assess enamel gloss changes induced by orthodontic bracket bonding with a light-cured composite or a light-cured resin-reinforced glass ionomer cement, after debonding and adhesive removal. The null hypothesis tested was that there is no difference in the aforementioned property between untreated and treated enamel.

Materials & Methods

Twenty recently extracted human upper premolars were cleaned with water and cotton rolls and maintained in deionized water. These teeth derived from adolescents scheduled to have first premolars extracted as part of their orthodontic treatment.

The criteria for tooth selection included: intact buccal enamel, with no caries or cracks due to the pressure of the extraction forceps, and not subjected to any pretreatment chemical agents, such as hydrogen peroxide. Teeth were anonymized by securing that no tracking of the donor could be made through storage (all teeth were stored as they were obtained in a single source).

The teeth were cleaned gently before the gloss measurement, which was done in wet specimens, with a gloss meter (Nuvo-Curve, Rhopoint, East Sussex, UK), after calibration with a standard black surface of 93% gloss. Measurements were made using the 60^{o} angle incident-reflection mode of the instrument (Figure 1). To standardize the area of analysis, each tooth was embedded in its custom-made jig made from vinyl polysiloxane matrix (Aquasil, Soft Putty / Regular Set, Konstanz, Germany), with a 3 x 3 mm frame, which coincided with this of the open window of the gloss meter. The use of this frame allowed for marking of the enamel surface intended for analysis, thereby facilitating repeated analysis of the same surface. This jig was used to place the frame over the aperture of the glossmeter at the same position at each time of measurement. Gloss was expressed in gloss units (GU) and measured in triplicate for each specimen and the mean value was used to characterize the tooth itself.

The teeth were divided into 2 groups of 10 teeth each. In group I, the premolar brackets (Unique, Werdenta, Germany / mesh base 4.2x4.4mm) were bonded with a light-cured composite (Transbond XT, 3M/Unitek, MN, USA) after conventional acid-etching with 37% orthophosphoric acid (Scotchbond™ Etchant Gel, 3M/Unitek) for 30 seconds. In group

II, a light-cured resin-reinforced glass ionomer cement (Fuji ORTHO™ LC, GC, Tokyo, Japan) was used without prior enamel treatment. However tooth surface was wiped with a moistened cotton roll immediately prior to bracket bonding.

All bonding/debonding procedures were performed by the same person (IS) according to manufacturers' instructions. Polymerization was initiated with a light source (Optilux 501, ORMCO, CA, USA) equipped with an 8 mm turbo light guide operated at boost mode in the following manner: each bond was irradiated for 5 sec from the gingival and 5 sec from the occlusal at an intensity of 900-1000mW/cm^2 as measured with a curing radiometer, incorporated in the light curing unit (Optilux).

All specimens were immersed in water (room temperature) for 48 hours and then brackets were debonded using a debonding plier (AEZ/ORMCO 803-0105), by pressing both mesial and distal wings in order to deform the bracket base. Removal of the remaining adhesive was performed with the use of an 18-fluted adhesive removal carbide bur (RENEW System; Reliance Orthodontic Products Inc., IL, USA), with a high speed handpiece (above 180,000 rpm)with water spray, until the enamel was again exposed. A second gloss evaluation was done on wet specimens at this stage (post-grinding interval).

Normality assumptions were checked on residuals through Shapiro-Wilk test and q-q plots for the outcome of interest (ie, difference in enamel gloss before and after bonding procedure). Due to the small sample size and the non- normal distribution of the data, non-parametric statistics were used. Descriptive statistics were used to present baseline and final values of gloss parameter, by mode of bonding procedure/ material (either light-cured composite or light-cured resin-reinforced glass ionomer cement). Mann–Whitney *U* test was used to check baseline similarity of groups. Linear regression with observed coefficients and 95% confidence Intervals (CIs) was used to assess the effect of mode of bonding procedure (material) on changes of gloss parameter values of the enamel as denoted by differences between before and after- bonding values. Standard errors (SE) were calculated using the bootstrap method with 500 replications (n=20).

The level of statistical significance was pre-specified at $p < 0.05$. Statistical analyses were performed with STATA version 15.1 software (Stata Corporation, College Station, Tex, USA).

Results

A total of 20 teeth were examined. Descriptive statistics (median, interquantile range, minimum, maximum) for the two groups before (baseline) and after bonding are presented in Table 1. No baseline value differences were detected among the groups for enamel gloss recordings ($p=0.27$).

The results of the linear model revealed a statistically significant difference among the tested groups for the outcome of interest (ie, change between baseline and treated enamel gloss values). Specifically, teeth bonded with the composite exhibited larger enamel gloss changes as compared to resin reinforced glass-ionomer cement by 0.74 GU (95% CIs: 0.10, 1.38; $p= 0.02$; Table 2, Figure 2).

Discussion

The hypothesis tested in this paper was not rejected. Significant surface alteration of the enamel regarding the effects on gloss were found after orthodontic bracket bonding and debonding, with a non-etching technique with the resin reinforced glass-ionomer cement and even larger alteration with the light-cured composite after conventional acid-etching.

In the case of orthodontic bonding with an acid-etching/composite technique, post-debonding enamel comprises of two entities: the tissue itself and the potential residual material remaining on enamel. Enamel acid-etching creates microporosities, and increases the surface area available for bonding, favoring the infiltration with bonding resins (tags). Even without subsequent bonding, changes were manifested in etched enamel after exposure to an oral environment i.e. greater values in amplitude and hybrid surface roughness parameters (Patcas et al. 2015) and differential light reflection in the form of a hyperreflexible zone extending as a 10 to 15μm wide band below the etched surface (Zentner & Duschner 1996).

After debonding, the surface is mainly composed of cut enamel infiltrated by resin tags, occupying the sites of enamel rods dissolved from acid-etching, and therefore, the refractive index of the region may be altered, modifying the diffusely reflected light component. Gloss values of specimen made from resin based composites are different than these measured from bovine enamel (Lefever et al. 2014; Silva et al. 2018). Enamel acid-etching and bonding with conventional composite resins has been shown to affect the enamel surface to a depth of 10-20 μm, whereas no filler particles are usually found in the resin tags, because of the dimensions of the reduced width of the tag, which does not exceed 3-5 μm, as well as the increased penetration of the unfilled, liquid resin, owing to its low viscosity. With the advent of nano-particles however, the interfacial properties are altered since these have been found to penetrate the tag (Jogrensen & Shimokobe 1975; Silverstone et al. 1975; Irinoda et al. 2000). Even colour changes of enamel associated with orthodontic bonding and clean-up procedures were reported (Ye et al. 2013; Boncuk et al. 2014).

Milder effects on gloss were found between treated and untreated enamel even in the glass-ionomer-bonded specimens without prior etching. With this technique, the predominating surface features following debonding and cleaning are those of altered enamel. This is because the mechanical retention facilitated by these materials is limited to the flow characteristics of the cement, which allow for adequate enamel wetting and establishment of a reversible hydrolytic molecular bond mechanism between ionized glass-ionomer carboxyl groups and enamel calcium (Eliades et al. 2001). Scanning electron microscopy revealed that enamel conditioning using the 10% polyacrylic acid before bonding with Fuji Ortho LC did not alter the fundamental configuration of the enamel surface (Shinya et al. 2008). After bracket bonding with this technique/debonding no resin tags were evident (Fjeld & Øgaard 2006).

The findings of the present study reflect enamel surface alterations since etching, cleaning and polishing procedures may affect the compositional pattern of enamel surfaces subjected to debonding. A statistically significant difference among the tested groups was demonstrated although the same adhesive grinding protocol was used, i.e. the bur may have removed the surface layer (which has been apparently affected by the bonding technique) or may have similarly affected the optical properties of the remaining enamel surface. It has been shown, that the clean-up technique may affect enamel colour after orthodontic bonding with composite resin or resin-modified glass ionomer cement (Ye et al. 2013; Boncuk et al. 2014). However, it is difficult to synthesise evidence relating to the postdebonding enamel morphology due to differences in enamel structural properties and standardization of the debonding technique. As far as tooth colour is concerned, Stainbuster burs are recommended for minimal colour change when brackets are bonded with an etch-and-rinse system (self- or not), however tungsten carbide burs should be used in cases bonded with resin-modified glass ionomer cement (Boncuk et al. 2014). Most authors agree that sufficient adhesive removal without enamel loss is rather difficult to achieve, regardless of the clean-up method (Hosein et al. 2004; Ryf et al. 2012). Less enamel loss occurs after bonding with a resin-modified glass ionomer cement, especially if a slow-speed tungsten carbide burs was used, in comparison with the high-speed tungsten carbide bur or the ultrasonic scaler (Hosein et al. 2004; Ireland et al. 2005). The use of ultraviolet light associated with a fluorescent adhesive allows for efficient adhesive removal compared with conventional lighting, without causing additional damage to the enamel (Ribeiro et al. 2017). Inasmuch, the present findings are specific to the debonding protocol used. A different debonding protocol might potentially produce somewhat different results.

The relationship between gloss perception, highlight disparity and roughness is rather complex (Methven & Chantler 2012). Although increased roughness is associated with decreased gloss and increased diffuse reflectance, which leads to an increased lightness (L*) in the Munsell system, no absolute information is available on the relationship between roughness and gloss. It is known, however, that material surfaces with nominal surface roughness half of the wavelength of blue light, that is approximately 0.2 μm, appear very glossy. Moreover, surface roughness in the enamel surfaces favors the accumulation of oral pigments, e.g., coffee, tea and tobacco, which may interfere with the optical appearance of enamel (Chung 1994; Davis et al. 1995; Eliades et al. 2001).

Gloss measurements were registered on wet specimens because of the formation of a thin layer of water on the surface, which possess a lower refraction index relative to either of the materials used in the study as well as enamel, owing to the development of surface tension at the water-air interface. Under these conditions, ρ increased as diffuse reflectance is decreased, an effect known as "wet roughness", which has been shown to increase the smoothness of surfaces in the oral cavity. This principle may find a useful application in removal of the remaining adhesive as noted by drying the adhesive surface to facilitate differentiation of resin remnants from enamel; in that case the adhesive appears to be whitish.

The measurements in the present experiment were made using the 60˚ angle incident-reflection mode of the gloss meter. The reflectance of a surface (ρ), defined as the ratio of reflected over incident light depends on the refraction index of the material and the angle of incidence (θ). Thus for a reflectance of 0^{o}, which would correspond to the case where the light hits the surface perpendicularly, ρ is given as (Darvell 2009):

$$\rho_o = (\frac{n_2 - n_1}{n_2 + n_1})^2$$

where:

n_1: the index of refraction of air, and

n_2: index of refraction for medium

It should be pointed out that the gloss measured by gloss meters is an approximation of the perceived gloss (human visual response), since the angular resolution of these instruments is higher than the one from the visual system. As a result, human eye perception of gloss meter differences may differ. The results of this study emphasize the requirement for further research regarding the relationship between the perceived and physical gloss as well as the physical roughness.

The present study is not free to limitations. The findings are based on a limited number of tested specimens and no a priori sample size calculation was conducted. However, due to the lack of similar studies in the literature to base our calculations on, any attempt could not have been based on valid pre-existing statistical inferences. Moreover, a linear regression model with derived standard errors based on the use of the bootstrap method was employed and might have partially accounted for the limited sample size.

Conclusion

Bracket bonding with two common bonding protocols (acid-etching with a light-cured composite vs. no etching with light-cured resin reinforced glass-ionomer cement) and subsequently debonding and adhesive removal with the same protocol induced enamel gloss changes.

Teeth bonded with composite / acid-etching exhibited larger enamel gloss changes as compared to resin reinforced glass-ionomer cement / no etching.

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FIGURE CAPTIONS

Figure 1

Schematic representation of the measurement of gloss with the 60^o angle mode, where Θi is the incidence angle and θr the reflectance angle and both equal 60^o.

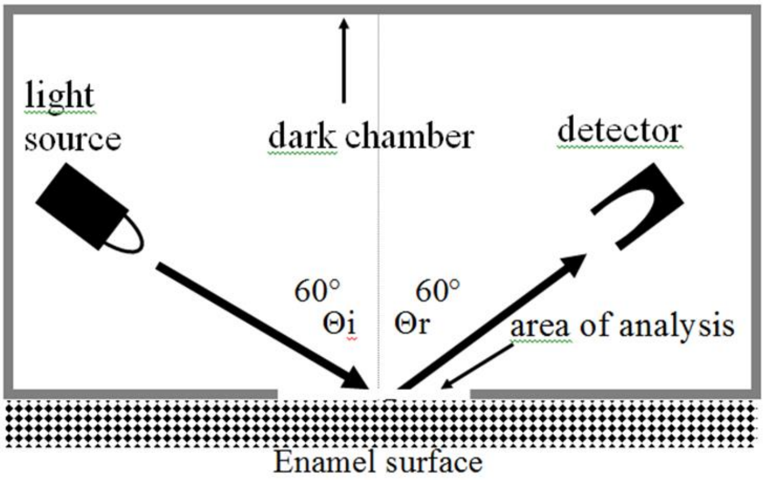

Figure 1

Figure 2

Predictive margins with 95%CIs for the effect of bonding material used on enamel gloss changes (in GU).

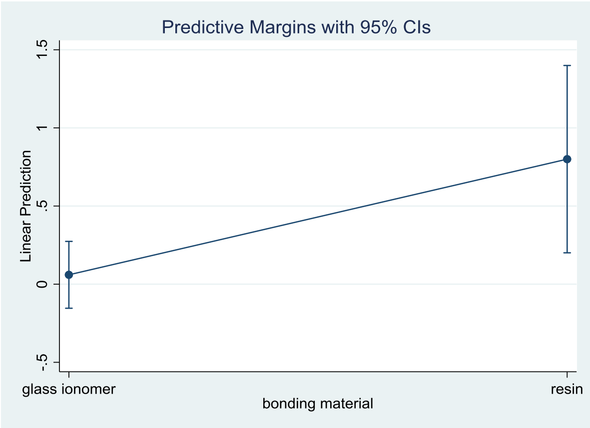

Table 1. Descriptive statistics for the examined enamel gloss parameter, by type of bonding material used (n=20)

*Mann–Whitney *U* test for comparison of baseline values

	Composite Resin (n=10)				**Resin- modified Glass Ionomer Cement (n=10)**				
	Median	Interquantile range (IQR)	Minimum	Maximum	Median	Interquantile range (IQR)	Minimum	Maximum	p-value*
before	6.50	2.30	3.90	8.80	6.00	2.50	3.90	7.60	0.27
after	6.15	2.70	3.40	7.30	5.95	2.80	3.60	8.20	

Table 2. Linear regression with observed coefficients and 95% confidence Intervals (CIs) for the effect of type of bonding material used on changes in enamel gloss. Standard errors (SE) were calculated using the bootstrap method with 500 replications (n=20).

	Observed Coefficient (β)	**95% CIs**	**p-value**
Group			
Glass ionomer	Reference		
Resin	0.74	0.10, 1.38	0.02